1909
G52

GOODSPEED

Live Loads Allowed On Floors of Buildings

Architectural Engineering

B. S.

1909

UNIVERSITY
OF
ILL. LIBRARY

UNIVERSITY OF ILLINOIS
LIBRARY

Class 1909
Book G62
Volume

Ja 09-20M

Digitized by the Internet Archive
in 2016

https://archive.org/details/liveloadsallowed00good

LIVE LOADS ALLOWED ON FLOORS OF BUILDINGS

BY

FRANK GOODSPEED

THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

ARCHITECTURAL ENGINEERING

IN THE

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED, JUNE, 1909

1335
[illegible]

1909
G62

UNIVERSITY OF ILLINOIS

June 1, 1909

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

FRANK GOODSPEED

ENTITLED **LIVE LOADS ALLOWED ON FLOORS OF BUILDINGS**

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Architectural Engineering

N. Clifford Ricker
Instructor in Charge

APPROVED: N. Clifford Ricker

HEAD OF DEPARTMENT OF Architecture

145227

UIUC

LIVE LOADS ALLOWED ON FLOORS.

A few articles have been written at various times in regard to the proper live load to be allowed as coming on the floors of buildings used for different purposes. These articles have been based largely on what was at the time, considered good practice, and the writer's personal judgement of the proper allowance therefore.

But in fact, some kinds of floor loads can be determined very accurately, and for others the possibility of overloading which may occur, make the determination of these loads more or less indefinite, so that a large factor of safety is imperative in providing for this possible excess of load. In still other cases, these loads may be suddenly and repeatedly applied, and they may be changed in position.

In small buildings and those of minor importance in their construction, it is not neccessary to determine closely the possible live loads, which may come on the floors. But in the case of high office buildings and others of the same type, especially those with steel skeleton construction, the architectural engineer is obliged to estimate their live loads very accurately, and he may not have at command the surplus strength which he is accustomed to use in working on smaller or frame buildings, for an excess of perhaps ten pounds per square foot on the floors of a tall skeleton building would make a difference in the cost of the completed structure, which would amount to thousands of dollars. Thus it is of vital importance that the architect should have an accurate understanding of the actual live loads in such structures, as well as of the requirements of the local building ordinances.

It is well known that the usual practice in computing stresses due to actual loads varies a great deal with engineers and architects, and that floor beams are sometimes made much stronger than the actual loads require to provide for any excessive vibration, to prevent deflection of the ceiling, and often to suffice in case of a changed use of the structure.

With the purpose of settling some of these frequently disputed questions of actual live loads, several investigations have been made by different men, and the results are published, which are of considerable value to the architect in computing these stresses. Professor Kernot of Victoria has made some experiments on the weight of a crowd of people(see American Architect, April 15,'93.), in which he packed sixteen young engineers of his class into an area of eighteen square feet, making an average load of 134.7 pounds per square foot. Mr. Binden B. Stoney, the author of a well known book on bridges and roofs, packed fifty laborers weighing in all 8404 pounds into an area of fifty-seven square feet, giving a load per square foot of 147.4 pounds. One of the most complete and most practical experiments ever made was executed under the direction of Mr. C. H. Blackall of Boston (see American Architect, Aug. 26,'93), in which three office buildings with a total of 210 offices were selected and the average weights of the various articles entering into the live load were taken. These average weights of furniture were the actual weights of the different pieces; weights of safes were given by the manufacturers; average weights of the books, partitions, etc. were taken, and the weights of the occupants were included. Such data wherever

possible represents the actual live loads existing in office buildings of this character, for the investigations were made without the influence of assumed data, and no attempt was made to prove any particular theory or assumption. Benjamin E. Winslow, a leading architectural engineer of Chicago has also compiled several tables of weights of actual live loads found on floors of various buildings, which are based upon actual observation and an experience extending over many years. The values given by the tables are therefore in accordance with good practice, and agree closely with those of other good authorities on this subject.

It is the object of this thesis to show by a table compiled from the building ordinances of the larger cities of the United States, the nature of the common practice, to show if possible why the given values are taken, and also to make apparent the large differences in live loads prescribed in different cities for the same types of buildings, in order to lead toward a general acceptance of standard live loads for the floors of different classes of buildings.

DWELLINGS.

From the table of loads taken from the city ordinances, it will be evident that the live floor load required in calculating the strength of floors of dwellings ranges from forty to eighty pounds per square foot. It is conclusively apparent that the maximum load of 147.4 pounds per square foot obtained by Mr. Stoney in his experiment by packing people into a small space, would be excessive, and that it was an impossible condition, which would certainly never occur in a residence.

In the ordinary dwelling it would be scarcely possible to find an average load of over 60 pounds per square foot and the possibility of sudden concentrations of live load on certain portions of the floor, or of the concentration of an excessive number of people in one room, as at a reception, is amply provided for by the large factor of safety used, which is an important consideration in all relating to the strength of materials. Boarding houses, lodging houses, tenement houses, apartment houses, flat buildings, and even hospitals and asylums require the same consideration as residences or dwellings. As a matter of fact these might even be considered as having smaller live loads than residences, for the probability of a reception being held in a boarding house, lodging house, etc. is small, and thus taking everything into consideration, it would appear that 50 or 60 pounds per square foot is sufficient for use as the maximum live load on floors of buildings of this class.

SCHOOL BUILDINGS.

In the ordinances examined, the maximum live load for school buildings was 100 pounds and the average was 76 pounds per square foot. The unit load in this and other cases of rooms with fixed seats, must actually be less than in almost any other class of buildings, except in case of a reception before the seats are fixed. The ordinary school room is designed to seat fifty pupils who weigh, on an average, 125 pounds each in high school; making a total of 6250 pounds. The usual average of floor area per pupil is taken at about 16 square feet, or 800 square feet for the total floor space. Thus making an average

live load due to pupils of only 7.81 pounds per square foot. Allowing for any concentrated loads which might come on the floor and taking into consideration a sudden crowding of pupils for a short time, 50 pounds per square foot, and also applying the deflection formula, may be taken as an ample allowance for live load to be used in calculating the floors of a school building.

CHURCHES.

In the case of churches, the conditions are much the same as in schools except the average weight of persons occupying the pews is more than the average weight of pupils in a school. Taking this into consideration and the fact that at weddings, funerals, etc. churches are oftentimes packed to the limit, 80 pounds per square foot will be amply sufficient as a basis for calculation of the strength of floors.

HOTELS.

Hotels, although open to the public, are rarely subjected to an extreme loading, except in the lobbies, dining rooms and corridors. In these places the live load may be safely assumed as 100 pounds per square foot, which allows a factor of safety amply sufficient. In the various rooms, parlors, private, etc. the same live loads may be assumed as for residences, to which these rooms are similar in purpose.

THEATRES AND MUSIC HALLS.

The question of theatres and music halls has been investigated by C. H. Blackall,(see American Architect,Aug.26,'93.) and he has observed, having repeatedly counted the number of persons in various portions of theatres and music halls, that the average load per square foot is not more than 40 or 50

pounds per square foot, and that the maximum unit load on the spans of beams is much less, in one case being as low as 10 pounds per square foot. He gives as an example the Bowdoin Square theatre of Boston; area, 3450 square feet. Taking from this area 696 square feet of aisles and 561 square feet of standing room at the rear of the orchestra circle leaves 1693 square feet as the seating area. There were 605 seats, weighing 20 pounds each and 20 pounds, the actual live load with each seat occupied, would average but 26 pounds per square foot. If the floor beams were 15 feet on centers and the audience was crowded into the aisles and standing room, which would be almost impossible, the load would be nearly 50 pounds per square foot, and were it possible to pack in the people as did Mr. Stoneyin his experiments, the maximum load on the beam would be only 93 pounds per square foot. Thus if 100 pounds live load per square foot is used to calculate the strength of theatre floors, it may be seen that an adequate factor of safety is included to provide for the weight of all structural materials.

STORES.

The question of the average live load on the floors of ordinary retail stores, stores where heavy materials are on sale, storehouses or warehouses for both light and heavy goods, light and heavy manufactories, can hardly be specified in an ordinance with any great accuracy, on account of the ambiguity of the meaning of "light" and "heavy" and the difficulty of determining the definite limits of either. While it is true that many ordinances specify definite loadings under these terms, still this is only to establish a maximum, and practically every building of this nature has to be specially

designed to suit the kind of business to be carried on therein, and the architect must know beforehand exactly what kind and quantity of goods the store, warehouse or factory is to contain; otherwise a great waste of material and money, or an unsafe building will result.

In larger cities the city building inspectors are required to see that no floor supports at any time a greater load than that for which it was designed. The ordinance also provides that signs shall be posted giving the allowable live load which may come on the floor and tenants must comply. All buildings in the loop district in Chicago must be examined by a licensed architect, who determines and certifies the live load per square foot which the floors can safely carry.

PUBLIC BUILDINGS AND ASSEMBLY HALLS.

Public buildings and assembly halls, when considered to have fixed seats, are calculated on the same basis as a theatre, but when the seats can be removed altogether the possibility of a large and densely crowd requires the use of a larger live load. Now if it be probable that every square foot of floor area were available and occupied, and if it be possible that people could pack themselves as densely as in Mr. Stoney's experiment, that would only require 147 pounds per square foot to be used as the maximum live load. But since it is a physical impossibility to pack an audience so densely, 112 pounds per square foot, which is a mean of the prescribed loads shown by the table of building ordinances, appears to offer a very reasonable basis for calculations, and this might even be safely reduced to 100 pounds per square foot in many cases, depending on the location of the building and the purposes of the meetings

and the class of the people that would occupy the rooms.

ARMORIES AND DRILL HALLS.

Armories, drill halls, and dance halls must be calculated for more than the actual live load which occurs on their floors. The important item to be considered here is indeed, the effect of impact or shock. The special allowance for impact in a drill hall is usually made by adding a certain proportion of the live load. Taking 25% as a reasonable allowance for effect of impact in a dance hall, adding this to the 100 pounds per square foot, taken as a reasonable quiet live load for an assembly hall, this gives 125 pounds per square foot, which is also a very liberal calculation basis for the floor.

The average of the loads prescribed by the ordinances is somewhat smaller for dance halls than for drill halls. This is correct, for the weight of the equipment, the uniform time, and the concentration and shock of a company while drilling causes a much greater stress than that produced by dancers. Moving cannon over the floors of a drill hall also causes heavy concentrated loads, and allowing for this by assuming 150 pounds per square foot, would appear to be a reasonable basis for calculation. Further, the effect on joists and floor of the entireweight of the cannon concentrated at two points must also be considered.

RIDING SCHOOLS.

The calculation of the floors of a riding school is based on the same principal as that of a drill hall or dance hall, and when the fact that although horses are heavier than men, they are not so close together, and their movements are less concerted than those of persons in a drill or dance hall,

it will be evident that these three classes of halls may be calculated for practically the same live load per square foot.

PRIVATE OR PUBLIC STABLES.

For private stables, the table of ordinances shows about 40 or 50 pounds per square foot to be used. A carriage horse weighs from 1100 to 1200 pounds and occupies about 50 square feet which would make the actual live load only 24 pounds per square foot. A carriage weighs from 500 to 800 pounds and occupies from 50 to 60 square feet, making the load 12 to 15 pounds per square foot for the carriage. Thus when allowance for shock caused by the motion of the horses is made, 40 pounds per square foot is about the maximum.

Public stables are required to have a much larger allowance for live loads. But when one considers that there is probability of a large number of horses being brought together at a public sale and that buyers and salesmen assembled there cause a greater load than would ordinarily occur, the load of 80 pounds specified by the Cleveland ordinances does not seem excessive.

Of course the question of moving loads is still an open one, no records, or data of any actual tests being available; the correct load to assume in these cases is one which has been found by experience and observation to be as nearly correct as possible.

Automobiles of the present day rarely weigh 4000 pounds and occupy a floor area of about 5'- 6" by 10'- 0", or 66 square feet, making a load per square foot of 66.6 pounds. In this case the allowance for shock may be less than that used for horses, so that the load of 80 pounds per square foot spec-

ified by the Cleveland ordinance will be amply sufficient for the live load to be used in calculating the floor of a garage.

MACHINE SHOPS AND MILLS.

The live loads for machine shops and mills are again still indeterminate, depending on the kind of machinery, it's weight, etc. to be employed in the shop or mill. Here again, the designer must ascertain beforehand just what will be placed on the floor and its weight, then using this data for calculating for each individual building. Again in this case, the building inspector must see that greater loads are not imposed on the floor than those for which they were designed.

OFFICE BUILDINGS.

One of the most important classes of buildings to be considered, on account of the modern steel skeleton construction, is the office building, and the investigations made by C. H. Blackall of Boston (see American Architect, Aug. 26,'93) to determine the actual live loads on the floors of office buildings constitute the best practical data for solving the problem of live load on floors that we have.

Three large office buildings in Boston were selected for the examination. The buildings were examined very carefully, each office successively, the dimensions of the rooms being taken, the nature of occupancy and of the contents were noted. The following average weights of articles of furniture were obtained:

Persons,	150	pounds.
Books (per running foot) including case	10	"
Roll top desks	250	"
Flat " "	125	"

Tables	75	pounds.
Chairs	15	"
Radiators (per running foot)	100	"
Letter press, including case,	100	"
Toilet wardrobes	150	"
Folding screen	10	"
Typewriter	25	"
Glazed partitions, per running foot,	75	"
Sofas	50	"
Chests, per foot of length,	15	"
Telephone stand	25	"
Counters, per foot,	50	"
Open rail, per foot,	3	"
Steel box safes	2500	"

Persons were averaged at 150 pounds each, although this is more than the average of a miscellaneous crowd of people. The greatest number of persons in each office at any one time was ascertained from the respective tenants and this was probably exceeded rather than underestimated. The sum of the assumed weights of the various contents was computed and the weights per square foot in the individual offices and the average weights per square foot in the entire building were calculated. The highest live load found was 40.2 pounds per square foot, and the lowest was 5 pounds per square foot. In only 12.4% of the offices was the average load greater than 25 pounds per square foot.

Tables of weights made up by C. H. Blackall from tests.

NUMBER OF OFFICES	TOTAL AREAS SQ.FT	AVER. AREA PER OFFICE SQ.FT.	TOTAL WEIGHT LBS.	MAXIMUM		AVERAGE OF WTS. PER FT. IN EACH OFFICE. LBS	MINIMUM	
				AVERAGE PER OFFICE. LBS	AVERAGE PER FOOT. LBS.		TOTAL WT. LBS	AVERAGE PER FOOT. LBS.
210	76,461	388.6	1,264,512	6,021.4	16.5	16,4	1,015,361	13.3

An average for ten of the offices with the heaviest floor loads was 33.3 pounds per square foot. The tenants of the 210 offices were as follows:

Lawyers,	111
Real Estate,	31
Stenographers,	7
Architects,	7
Manufacturing Companies,	15
Railroads,	10
Brokers,	5
Insurance,	3
Banks,	3
Miscellaneous,	18

The lawyers' offices were most numerous and were most heavily loaded on account of the number of safes and the quantities of law books required by each lawyer.

Of course the loads specified by the building ordinances are not intended to represent the actual live loads on a floor, but they are designed to contain a certain factor of safety. They also guard against an injurious deflection of the ceiling and so they are made sufficiently large to prevent any undue vibration. Floors are also expected to act somewhat as horizontal wind bracing. This fact accounts for the seeming discrepancy between the actual live load on a floor and the live load required by an ordinance. These loads also provide for a reasonable change in the use of a building.

In this thesis it is not my intention to criticize the usual requirements, for the live loads specified in the various ordinances result from much thought and labor by the builders,

architects, and engineers who prepared such ordinances. Rather it is my purpose to illustrate the diversity of opinions and of practice in many cases, and to endeavor to reach some common basis, whereby specified live loads may be made more nearly uniform in all ordinances.

It is further evident that these building ordinances of the various cities should be uniformly harmonized for the entire country, perhaps on the basis of the excellent model code prepared for this purpose by the executive committee of the Underwriters Association of New York City. To show this existing need is one of the chief aims of this thesis.

Floor Loads for Buildings of ordinary Construction

Kind of Building	Dead load Fr.	Dead load To.	Live load Fr.	Live load To.	Total load Fr.	Total load To.
Plastered Ceilings	10	15	0	10	10	25
Shingle Roofs- Skylights-	10	15	25	30	35	45
Slate Tile or flat Gravel Roofs	15	25	25	30	40	55
Country Houses	15	20	40	50	55	70
Dwellings Residences Boarding + Lodging Houses	15	20	40	60	60	80
Apartment + Tenement Houses	15	20	40	60	60	80
Hotels Office Bldgs. Hospitals	15	20	50	70	65	90
Schools Colleges and Dormitories	20	25	50	70	70	95
Porches + Verandas	15	20	70	90	85	110
Private Stables + Carriage Houses	20	25	80	100	100	125
Ordinary + Department Stores	20	25	80	100	100	125
Tailor Shops + Shops for light Work	20	25	80	100	100	125
Churches + Theaters with fixed Seats	20	25	80	100	100	125
Light Manufacturing Buildings	20	25	80	100	100	125
Lobbies + Stairs in public Buildings	20	25	80	100	100	125
Fire escapes + Balconies	15	20	100	120	115	140
Public Libraries Armories Grand Stands	20	25	100	120	120	145
Floors Stable rooms for large Livery Stables	20	25	100	120	120	145
Furniture and other light Storage	20	25	100	120	120	145
Light Printing Establishments + Floorwalks for Highway Bridges	20	25	100	120	120	145
Court Houses, City Halls, Jails	20	25	100	120	120	145
Assembly Halls without fixed Seats, Hay lofts	20	25	100	120	120	145
Dancehalls, Drillhalls + Gymnasioms	20	25	120	150	140	175
Factories for heavy Work light Warehouses	20	25	120	150	140	175
Merchantile Buildings	20	25	150	200	170	225
Light Machinery ordinary Warehouses	25	30	150	200	175	230
General Teaming with Trucks	20	30	200	250	220	280
Side Walks	100	120	200	250	300	375
Heavy Storage, Power Houses, Foundries	50	40	200	400	250	440
Alley Driveways	100	150	250	300	350	450
Storage of Paper, heavy Warehouses	30	40	300	500	330	540
Heavy Machinery Printing Presses	30	40	400	500	430	540
Horizontal Wind for all Buildings more than 1½ x the Width in Height						25

Special Loads + Weights of Building Materials

	Total Weight	Concentrated load	Load per □ Ft.	Load per lineal Ft.	Load per Cubic Ft.
Heavy Machinery + heavy Safes	ac	tu	al	Weight	
Heaviest portable Safes	6000				
Coal Wagons	6000	4000			
Automobiles	6000	1500			
Ordinary Safes for Offices	5000	4000			
" " " Dwellings	2000	1500			
Cases with Drawers					20
Book Cases for each Foot in Height			25-30	25-30	25-30
Book Cases f. e. Ft. in Ht. on each Side of Partition			25-30	50-60	25-30
Pianos from 800 to	1200				
Furniture in Dwellings Maximum			10		
4" Partition Stud plastered 2 Sides			15		
6" " " " "			20		
Grain					48
Hay					18
oats					24
Snow freshly fallen					12
" wet					48
Plastering — Cement Floor					90-110
Asphalt Flooring					80-100
Tile Flooring					140-160
Terra Cotta Facing hollow, 4" thick					80-100

Thickness of flat Tile Arch	6"	7"	8"	9"	10"	12"	15"	16"
Weight pr. cub. Ft.	23-27	25-30	26-30	27-33	28-35	30-40	40-50	42-52
Thickness of Tile Part'n	2"	3"	4"	5"	6"	8"	Furr 1½"	Tile 2"
Weight pr. □ Ft	10-12	13-16	15-18	17-20	20-24	25-30	7	8
Thickness of Book Tile	2"	2½"	3"	3½"	4"			
Weight pr. □ Ft.	9-10	11-13	13-17	15-18	17-20			

Weight of a Crowd of People each Person weighing 150 Lbs

Distance apart Ctr.-Ctr.	12"	13"	14"	15"	16"	17"	18"	19"	20"	21"	22"	23"	24"
Weight pr. □ Ft.	150	127	110	96	84	75	66	59	54	49	44	40	37½

Compiled by Mr. Benj. E. Winslow.

LIVE LOADS ON FLOORS

LBS. PER SQ. FT.
FROM BUILDING ORDINANCES

CITIES	Dwellings	Boarding + Lodging House	Tenement House	Schools	Churches	Hotels	Hospitals + Asylums	Apartment Houses	Theaters	Ordinary Retail Stores	Storehouse or Warehouse	Storage Light	Public Bldgs + Assembly Halls	Light Manufacturing	Office Buildings	Flat Building	Drill Rooms + Armories	Dance Halls	Riding School	Stores Heavy Materials	Cafes + Dining Rms	Stables Public	Stables Private	Factories Heavy Materials	Machine Shops	Mills	Halls Fixed Seats	Office Bldg 1st Floors	Corriders + Halls	Museums + Libraries	Court Rms	R.R. Depot		Work Shops	
																																Fixed Seats	Movable Seats	1st floor	Above 1st floor
London	50	50	50	85	100	50		50	100	100	125	125	100	125	100						100								School 75 Office 100						
New York	60	60	60	75		60		60		120	150	120	95	120	75							75		150				150							
Chicago	40	50	40	75	100	50	50	40	100	100		100	100	100	50							100	40												
Philadelphia	70		70			70	70	70		120	150		120	120	100									150											
Boston	50			60		100				125	250		125		100		250	200	200	250															
Cleveland	40		50	60	80	50	60		80	100	200		100		60			150				80		200			80		Office 100 Hotel 80	100	100	80	100	125	100
Buffalo	70	70		100	100	70	70	70	100	120	150	120	100	120	70	40						120	40												
Pittsburgh	70										200		150											200											
New Orleans	80										250				125																				
Milwaukee	40	40	40	50	80	40		40	80	100			100	100	60																				
Jersey City	60	60	60	75		60		60		120	150	120	90	120	75							75		150											
Minneapolis	50	50	50	100		50	50	50		100	200	100	125	100	75					200		85		200				150							
Providence	70	70	70	100	125	70		70	125	50	250		125	100			250			150		70		150	250	150									
Indianapolis	50	50	50	100			50	50		100	200	100	125	100	75					200		85		200				150							
Kansas City	80	80	80							100	250			100			250		250						250										
Rochester	50		50	70	70	50	50	50	80	100	150		70	100	70	50		70				100	50	150			70								
Denver	40	50	40	50	80	50			80		150				70	40	150	120									80		120						
Toledo	40	40	40	50	80	40		40	80	100			100	100	60		175	175	175																
Worcester	70										250		125		100					250				250											
Fall River	75	75	75							150	250		150	150	150									250	250	250									
Omaha	50					75				150	250		125		75		250												Hotels 125						
Los Angeles	60					60	60	60		150	250		125		75	60		125		250				250					Public B'ldgs. + Hotels 125						
Toronto	50	50	50	85	100	50	50		100	100	125	125	100	125	100						100							125	School 75 Office 100						
Vancouver	50	50	50	85	100	50	50		100	100	150		100	150	100						100								School 150 Hotels 75						
Montreal	70									150	150		125	150	100																				
Average	57	56	54	76	92	58	56	55	93	117	194	115	112	116	85	47	221	140	208	216	100	88	43	191	250	200	77	145							

UNIVERSITY OF ILLINOIS-URBANA
3 0112 086826010